Estimate the Durability of Rice Husk Ash Concrete Subjected to Sulfate Attack Through Wetting and Drying Cyclic

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Abstract It is well known that aggressive environments like the sulfate attack are the major factor affecting the durability of concrete. Thus, this research was carried out to estimate the durability of rice husk ash (RHA) concrete exposed to sodium sulfate attack through wetting and drying cyclic. Five levels of cement replacement namely 0, 10, 20, 30 and 40% (by weight) were studied. After being kept in the sodium sulfate solution for 3, 7, 28, 56, 90 and 180 days, the RHA concrete specimens were evaluated based on the rapid chloride permeability and its correlation. It was found that the total charge passed in Portland cement concrete was higher than that of RHA-blended cement concrete. However, it continued to decrease along with increasing levels of RHA replacement. In addition, the use of 40% RHA in the cement resulted in better resistance to sulfate attack when the concrete specimen was exposed to the wetting and drying cycles. It can be concluded that the use of 10 to 40% RHA effectively decreased the penetration depth (charge passed) in the concrete under sulfate attack.

Keywords Durability · Sulfate attack · RCPT · Wetting · Drying

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1 Introduction

RHA is known to be superior to other supplementary materials such as; slag, palm oil fuel ash (POFA), silica fume, and fly ash (FA). Due to its high pozzolanic activity, both strength and durability of concrete are improved [10]. During the past decades, extensive research has been carried out to investigate the performance of RHA in relation to the properties of concrete [5]. The use of RHA as a mineral admixture for concrete is not new and considerable amount of data has been published with regard to its influence on the behavior of concrete [2]. RHA, which is rich in silica, is obtained by burning rice husks to remove volatile carbons such as cellulose and lignin. Della et al. (2002) reported that for incineration temperatures of up to 700 °C for 6 h, 95% silica powder, predominantly in amorphous form, could be produced. It is generally agreed upon that the use of RHA whose main chemical composition of which is silica, helps to improve the durability of concrete especially when exposed to chloride and sulfate attacks [12, 15].

Pozzolanic materials such as fly ash (FA), silica fume, and RHA, which are mainly silicates when added to cement, react with $Ca(OH)_2$ to form additional calcium silicate hydrates in the hydrated cement matrix [13]. Romano et al. [16] reported that calcium silicates (Ca_3SiO_5) are the most important components of pozzolanic materials and are responsible for most of concrete properties such as the durability. Bui et al. [6] reported that the added pozzolanic materials, which are finer than cement particles, fill the pores and improve the particle packing of cement paste in the transition zone between aggregates and cement paste, leading to the reduction of permeability. When fine pozzolanic particles are dispersed in the paste, they generate a large number of nucleation sites for the precipitation of the hydration products. Thus, the addition of pozzolanic materials to Portland cement increases its durability when compared to the controlled specimen [11].

Cyclic wetting and drying process accelerate durability problem because it subjects the concrete to the movement and accumulation of harmful materials, such as sulfates, alkaline, acids, and chlorides. Sahmaran et al. [17] reported that continuous immersion of the specimens in chloride solution does not necessarily represent the field conditions. However, the specimens are subjected to aggressive environmental with wetting–drying cyclic and simulate in the laboratory are common methods of accelerating the tests [9, 18]. According to [8], continuous immersion of specimens does not necessarily represent the field conditions because generally, the concentration and pH of the site generally remains constant. Conversely, simulated field exposure conditions in the laboratory with the application of wetting and drying cycles are common methods of accelerating the tests [7, 14]. Based on the related literature presented, there are no information is available on the effect of RHA blended cement subjected to sulfate solution with wetting and drying cycles under laboratory simulation. Therefore, there is a need for further investigation on the durability of RHA concrete subjected to sulfate attack through wetting and drying cyclic.

2 Experimental Study

2.1 Raw Materials

Locally available ordinary Portland cement (OPC) used in this investigation was supplied in one batch for the entire study to ensure consistent quality and properties. It was revealed that the main constituents of cement were CaO (70%), SiO_2 (18%), Al_2O_3 (4%), Fe_2O_3 (3.2%), MgO (1.5%), and SO_3 (3.6%), respectively. Furthermore, RHA was produced by controlled burning of the Rice husk with the temperature of 700 °C (6 h). The ash was then ground using a laboratory ball mill with porcelain balls until it met the fineness as requirement by ASTM C 618. RHA used was mainly amorphous silica with main oxides namely SiO_2, Al_2O_3, and Fe_2O_3 comprised 92% which it met the standard of ASTM C 618 [4]. A coarse aggregate with a single size of 20 mm was used while local natural sand derived from granite was used as the fine aggregate in the concrete mixtures. The coarse and fine aggregates each had a specific gravity of 2.65, and water absorption rates of 0.47 and 0.85%, correspondingly.

2.2 Sodium Sulfate

Sodium sulfate is the sodium salt of sulfuric acid. It is a white crystalline solid of formula Na_2SO_4. At the laboratory, the sodium sulfate solution was prepared by mixing the chemical with distilled water at 5% (weight of volume) and it was used to represent extremely severe sulfate exposure as stated by ACI 318–08 [1]. At each cycle, the solution was replaced by a freshly prepared one or based on the change in the pH of the solution.

2.3 Concrete Mix Design

A control mix was prepared using OPC. RHA replacement levels of 10, 20, 30 and 40% by weight of cement were applied. These are referred to as RHA10, RHA20, RHA30 and RHA40, respectively. The RHA was thoroughly mixed with OPC in blended cement, and water was added to the mixer. Superplasticiser was added to the mix to maintain slump flow values. When the mixtures were prepared, the concrete was cured in water maintained at room temperature for a minimum of 28 days to achieve target strength of 40 MPa. After 28 days of curing under water, the specimens were subjected to sulfate solution via wetting–drying cycles. The tests were conducted at the ages of 3, 7, 28, 56, 90, and 180 days.

2.4 Wetting-Drying Cyclic Test

Cyclic wetting and drying is a main problem for concrete structure when exposed to sulfate attack. Cyclic tests were performed to obtain an understanding of the mechanisms causing the aggressive environment of concrete during the wetting and drying phases of the cycle. Wetting period with an average of 15 h was used throughout this investigation, followed by 9 h of drying per day. Time intervals of wetting and drying cycles were considered to simulate the Malaysian conditions of a tropical rainforest climate.

2.5 Rapid Chloride Permeability Test

The test was conducted according to the ASTM test method C1202 [3]. Concrete specimens of 100 mm diameter with 50 mm thickness were used. In the RCPT test, the concrete specimens were conditioned using a vacuum pressure of 1 mmHg (133 MPa) on the dry specimens and maintained for 3 h. The specimens were treated under vacuum saturation for a period of 1 h after adding water, and further soaking under water for a period of 18 h. The specimens were then placed into the RCPT instrument. Then, the current was measured and recorded at 5 min intervals with a data logger. The total charge passed through the specimen was computed, and the chloride ion penetrability was evaluated qualitatively.

3 Results and Discussion

3.1 Total Charge Passed

Generally, the total charge passed of RHA blended cement concrete continuously decrease with an up to 40% increase in RHA content as illustrated in Fig. 1. For instance, at 28 days of exposure, the total charge passed of 10% replacement RHA in cement was 1967 Coulombs (C), whereas at 20, 30, and 40% RHA, the corresponding total charge passed was 1054, 811 and 753 C, respectively. Hence, a 10% increase in RHA content can reduce of total charge passed in the range of 7.15 to 46.40%. At all RHA contents investigated, a 10% replacement was recorded as the highest charge passed, whereas 40% was recorded as the lowest total charge passed. This explains the trend exhibited in Fig. 1. On the other hand, the controlled concrete specimen presented the greatest average total charge passed compared with RHA cement concrete. For instance, at the age of 180 days, the average total charge passed in the OPC concrete was 51.78% more than that in the RHA10 concrete. It can be seen in Fig. 1, the rapid chloride permeability decreased with an

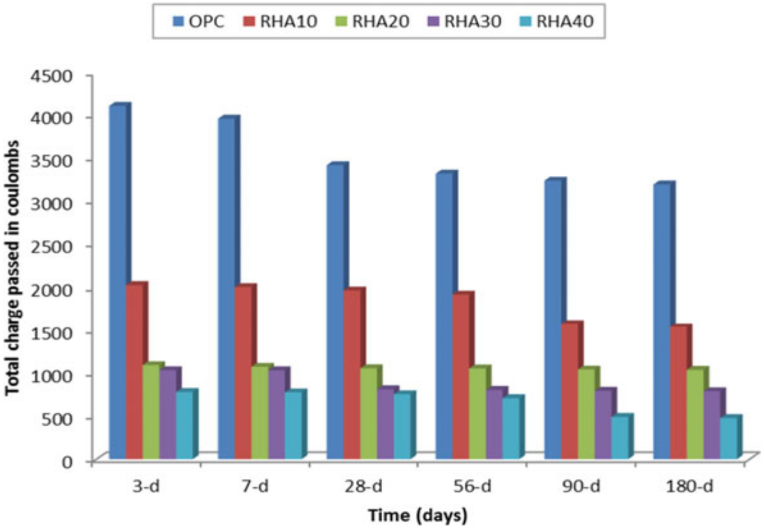

Fig. 1 Total charge passed of OPC and RHA blended cement concrete under sulfate attack via wetting–drying cyclic

increase in age. For example, for RHA10 concrete, the total charge passed was reduced from 2030 to 1538 C as the age increased from 3 to 180 days.

3.2 *Classification of Charge Passed*

According to the ASTM C1202-10 classification ranges, the chloride ion penetrability is considered "high" when the total charge passed is higher than 4000 C. When the total charge passed values are between 2000–4000, 1000–2000 and, 100–1000 C, as well as less than 100 C, concrete can be classified as "moderate", "low", "very low", and "negligible", respectively. It can be observed from the data presented in Table 1 that the charge passed of OPC concrete changed from "high" to "moderate" due to an increase in age ranging from 3 to 180 days. Conversely, replacing RHA reduced drastically the chloride ion penetrability of concrete from "moderate" to "very low" ratings from higher to lower replacement levels, respectively. For instance, at 20% replacement level, almost all the total charge passed was less than 2000 C, and chloride penetration was classified as "low". However, when the replacement level increased up to 40%, the total charge passed was lower than 1000 C, and concrete can be classified as "very low".

Table 1 Chloride permeability as per ASTM C 1202

RHA (%)	Total charge passed in coulombs					
	3-d	Risk of penetration	7-d	Risk of penetration	28-d	Risk of penetration
0	4101	High	3953	Moderate	3414	Moderate
10	2030	Moderate	2007	Moderate	1967	Low
20	1090	Low	1071	Low	1054	Low
30	1032	Low	1030	Low	811	Very low
40	778	Very low	774	Very Low	753	Very Low
RHA (%)	56-d	Risk of penetration	90-d	Risk of penetration	180-d	Risk of penetration
0	3315	Moderate	3234	Moderate	3189	Moderate
10	1920	Low	1575	Low	1538	Low
20	1052	Low	1040	Low	1035	Low
30	802	Very low	792	Very low	788	Very low
40	707	Very low	490	Very low	477	Very low

3.3 Correlation Between Charge Passed, Current and Temperature

The curves in Fig. 2 illustrate the relationship between current rate and time for all mixes, showing a consistent trend for majority of the mixes. However, using RHA blended cement showed the positive effect of decreasing current rate, which resulted in reduced total charge passed. Generally, by adding up to 40% of RHA, the specimen exhibited the lowest current rate compared with other mixes. On the other hand, increasing current rate was obtained for all concrete specimens as the time increased. The average current of OPC concrete was 1.25, 20.08, 34.19%, and 40.80% higher than those of RHA10, RHA20, RHA30 and RHA40 cement concrete, respectively. As such, the added RHA in the cement concrete reduced the current rate of specimens even when subjected to sulfate solution with drying-wetting rotations.

3.4 Correlation Between Charge Passed, Current and Time

Clearly, the total charge passed of OPC and RHA cement concrete increased proportionally over time as show in Fig. 3. The rate of increase in total charge passed with respect to time of OPC concrete was also higher than that of the other concrete specimens. Among the replacement levels, the RHA40 blended cement concrete exhibited the lowest rate of increase, followed by RHA30, RHA20, and RHA10. From the slope of the graph shown in Table 2, the total charge passed and

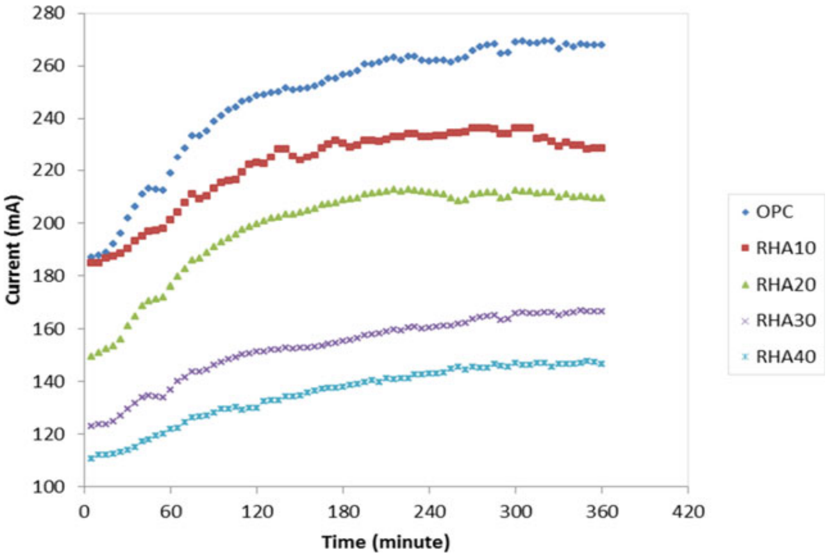

Fig. 2 Relationship between current and time of OPC and RHA blended cement concrete under sulfate attack via wetting–drying cyclic

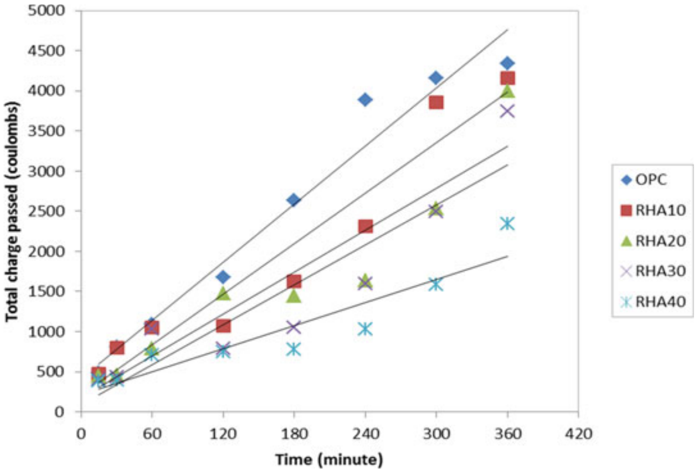

Fig. 3 Relationship between total charge passed and time of OPC and RHA blended cement concrete under sulfate attack via wetting–drying cyclic

Table 2 Coefficients of the linear relationship between total charge passed and time

Mixture type	Independent variable, x	Dependent variable, y	Constant		R^2
			c	m	
OPC	Time	Total charge passed	411.91	12.09	0.97
RHA10			202.93	10.52	0.92
RHA20			169.66	8.73	0.89
RHA30			91.92	8.29	0.86
RHA40			212.61	4.81	0.86

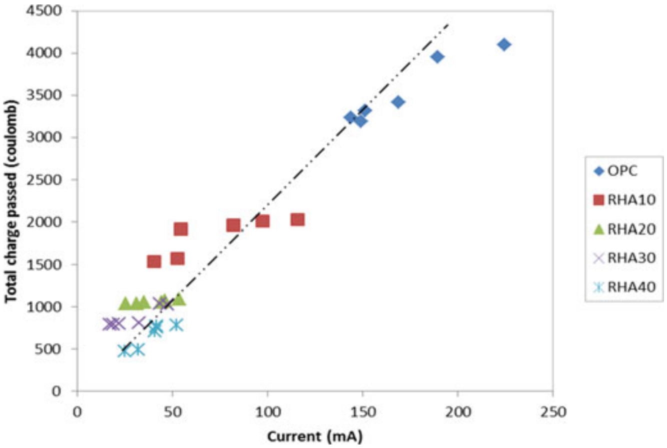

Fig. 4 Relationship between total charge passed and current of OPC and RHA blended cement concrete under sulfate attack via wetting–drying cyclic

time were linearly correlated with R-Square values exceeding 0.86. In addition, the effect of RHA on chloride ion permeability was significant. In order to illustrate the relationship between the total charge passed and current based on the experimental data, the total charge passed was graphically correlated with the current as presented in Fig. 4. Table 3 shows the linear regression parameters linking total charge passed and current. The different percentages of the RHA mixes showed R-Square values beyond 0.85, which also showed other parameters of the linear equation.

Table 3 Coefficients of the linear relationship between total charge passed and current

Mixture type	Independent variable, x	Dependent variable, y	Constant		R^2
			c	m	
OPC	Current	Total charge passed	1462	12.1	0.92
RHA10			1378	6.24	0.88
RHA20			985	1.84	0.89
RHA30			138	13.51	0.85
RHA40			613	8.7	0.87

4 Conclusions

Rice husk ask proved to be a suitable replacement material for cement, and helped to reduce the total charge passed and increased the durability of concrete under sulfate attack through wetting and drying cyclic. A higher RHA replacement level as the results decreased the total charge passed, thus enhancing the resistance of concrete to sulfate attack. The increase of RHA replacement in concrete from 10 to 40% have the positive effect of decreasing current rate, which resulted in reduced total charge passed.

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